Coastal Heritage

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Sea-Level RISE

Adapting to a Changing Coast

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ON THE COVER:

Hunting Island State Park in Beaufort County has lost 12 cabins to erosion since 2008 because of natural changes in local currents and sand supply to the beach. In the future, many more coastal structures will be threatened by a combination of regional or local shoreline changes and global sea-level rise.

PHOTO/WADE SPEES

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S.C. Sea Grant Consortium

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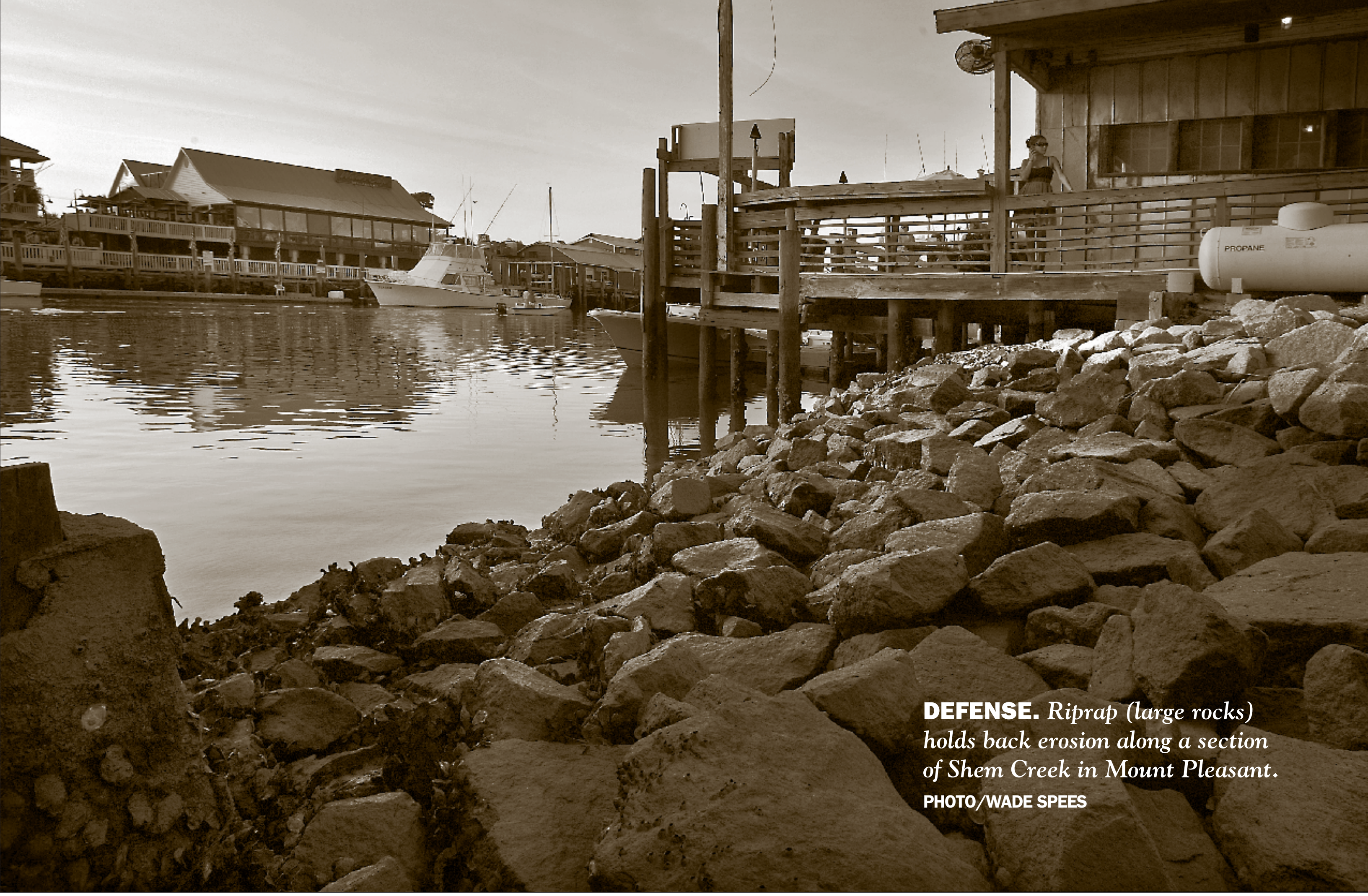
S.C. Sea Grant Consortium
287 Meeting Street
Charleston, S.C. 29401
phone: (843) 953-2078
e-mail: Annette.Dunmeyer@scseagrant.org

Executive Director
M. Richard DeVoe

Director of Communications
Susan Ferris Hill

Editor
John H. Tibbetts

Art Director
Sara Dwyer
Sara Dwyer Design, LLC



DEFENSE. *Riprap (large rocks) holds back erosion along a section of Shem Creek in Mount Pleasant.*
PHOTO/WADE SPEES

Sea-Level Rise
Adapting to a Changing Coast

by John H. Tibbetts

A high tide slaps against wooden pilings beneath Red's Ice House, a lively bistro along Shem Creek, a brief boat ride from Charleston Harbor. Commercial fishermen once bought fuel and ice here, but the local fishing industry is almost gone, squeezed out by global competition. Now restaurants flourish on this stretch of Shem Creek, where riprap (large rocks) holds back shoreline erosion.

Decades ago, this waterfront was salt marsh. Then it was filled in to create dry land for fishing shacks. But the ocean wants to take it back, and someday it will. High tides over time will get higher along the U.S. Atlantic and Gulf coasts, scientists say, because warming seawater is expanding and polar ice is disappearing at an accelerating pace, raising global sea level.

"The land here is sinking—or subsiding—while global sea level is rising," says Clay McCoy, coastal-processes specialist with the S.C. Sea Grant Extension Program.

These two influences—local and global—have added up to about a foot of "relative sea-level rise" over the past 70 years in Charleston Harbor. Delta sediments are naturally compressing, which has made the Charleston area sink roughly six inches. Meanwhile, global sea level has risen about six inches.

Someday low-elevation places like Shem Creek will become flashpoints of sea-level rise. In an effort to fight erosion, property owners have armored many estuarine shorelines with riprap, bulkheads (wooden seawalls), or other hard structures, and they have pumped sand onto beaches, building shorelines higher and farther seaward.

But climate change is escalating much faster than many scientists thought possible just a few years ago, and sea-level rise will accelerate as a result, according to Christopher Field, a biologist at Stanford University, who is a lead member of the Intergovernmental Panel on Climate Change (IPCC), which published its most recent global assessment in 2007.

The IPCC assessment was a state-of-the-science report providing scenarios of how climate change would alter ecosystems, natural resources, and societies around the world. But as soon as it was published, the report was outdated. Mid-year 2006 was the cut-off for scientific studies to be included. The next assessment is due in 2014.

Over the past three years, new findings have continued pouring in from researchers around the world, and modelers have entered these data into their supercomputers, creating more recent snap-shots of climate change.

It's a troubling picture, scientists agree. Climate disruption is moving at a greater pace than even the most extreme IPCC projections. "We're on a trajectory of climate change," says Field, "that's beyond the range that's been explored" by computer models.

A rapidly increasing volume of carbon dioxide (CO_2) is pouring into the atmosphere from smokestacks, tailpipes, and other sources. The greenhouse gas captures a portion of the sun's radiant energy and, in turn, raises the temperature of the Earth. (The most important greenhouse gas is CO_2; others include water vapor, methane, and nitrous oxide.) Much of the CO_2 that we release today into the atmosphere remains there for tens of thousands of years.

The Earth's temperature has already risen 0.7° Celsius (1.2° Fahrenheit) since 1950. By the middle of this century, global temperature would rise at least another 2° C (3.6° F) under the IPCC's business-as-usual scenario. That is, unless the international community takes quick, decisive actions to slow greenhouse emissions, the Earth is on a track toward dangerous warming, causing increasing storms, droughts, floods, and other natural disasters, the IPCC warned.

It was an alarm that captured the public's attention. But now some scientists say that the IPCC underestimated the problem.

Recent data show that the world's rising economic powers, including China and India, industrialized at an unexpectedly blistering pace from 2000 through 2007, much faster than the IPCC forecast. China and India rely primarily on coal generation for electricity, and coal produces the most CO_2 per unit of energy. The World Bank forecasts that China's economy, the world's fourth largest, will continue to grow substantially—6.5 percent—in 2009 despite the global financial crisis.

WASHED AWAY. ***Rapidly eroding beaches, like this section of Hunting Island State Park, will probably continue to be among the most vulnerable shorelines as climate change drives up sea level.***
PHOTO/WADE SPEES

Still, over the past few years, "what is most remarkable are changes in the cryosphere and sea-level rise," says Field. The cryosphere—the world of ice and snow, including the ice sheets of Antarctica and Greenland—is being disrupted by warming.

"Ice sheets are shrinking faster and faster, and we will see a one-meter [more than three feet] global sea-level rise by the end of the century—that's almost certain," says Robert Bindschadler, a glaciologist and chief scientist at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center in Greenbelt, Maryland.

But it's possible that global sea level could rise by two meters (nearly seven feet) by 2100, he adds.

Thermal expansion accounts for about half of today's global sea-level rise. Loss of freshwater from glaciers and ice sheets accounts for the other half. But glaciers and ice sheets will become a much larger proportion of global sea-level rise in the future. Losses of polar ice sheets will accelerate during this century and afterwards, sending vast volumes of freshwater into the ocean.

Global sea level probably won't rise more than six or seven feet by 2100, glaciologists say. There is a time lag between global warming and sea-level rise. One reason is that land-based polar ice sheets appear to have physical limits on how quickly they can shrink and lose water to the ocean.

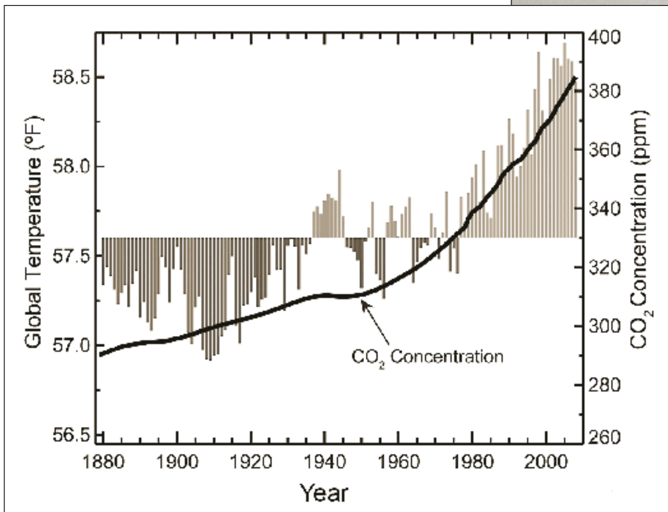
"There's no question about the direction we're heading," says Bindschadler. "Every time that the planet has gotten warmer, ice sheets have melted. The question is how much and how fast they will melt."

Communities on U.S. Atlantic and Gulf shorelines have three alternatives to respond to rising sea level. The first is to relocate buildings, businesses, and infrastructure inland from the ocean or, in some cases, to elevate them temporarily—until they too must be moved inland. The second is to hold back the sea by engineering the coast, which has become a more common approach. The third is some combination of these two alternatives.

How quickly would three feet of global sea-level rise affect coastal communities? There's not a single answer.

"Local impacts of sea-level rise are fantastically complex," says S.C. Sea Grant Consortium researcher Paul Gayes, director of the Center for Marine and Wetland Studies at Coastal Carolina University.

Different shorelines can have



Since 1880, global mean temperature has risen overall in tandem with increased atmospheric carbon-dioxide concentration.
CHART/NOAA, NATIONAL CLIMATIC DATA CENTER

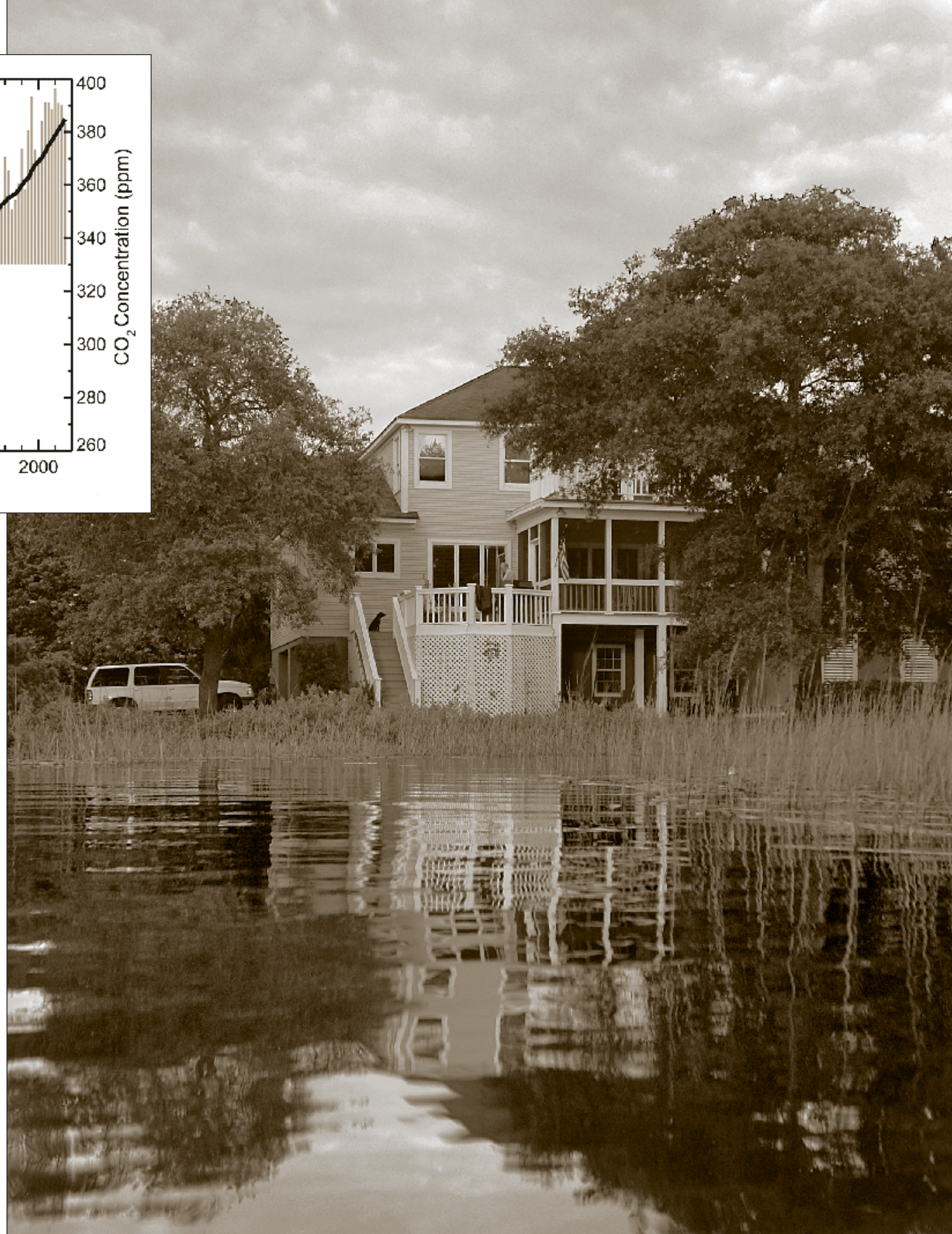
starkly different rates of change. Some beaches, like those of Kiawah Island, are steadily accreting, while others, such as some on Hunting Island, are eroding at a precipitous pace. The shorelines that are most vulnerable today would probably continue to be the most vulnerable in the future, Gayes says.

A three-feet rise in global sea level would displace millions of people around the world from low-elevation coastlines and on oceanic islands. It would contaminate some coastal freshwater supplies with salt water. It would increase coastal flooding, shrink barrier islands, and drown many salt marshes on the U.S. Gulf and Atlantic shorelines. It would also amplify extreme events such as tropical cyclones that would often cause rapid, dramatic shoreline changes.

A number of governments have taken steps in recent years to address sea-level rise.

- The Rhode Island Coastal Resources Management Council is drafting new rules that would require houses, roads, businesses, and all other structures to be sited and built to accommodate an expected three-to-five foot rise in relative sea level by 2100.
- The New York City Department of Environmental Protection is studying future storm-surge scenarios and considering building floodwalls to protect critical infrastructure such as waste-treatment plants. The city is also studying the potential for constructing a major tidal floodgate across the Verizano Narrows to protect Manhattan.
- South Carolina has established a Shoreline Change Advisory Committee to consider longstanding management practices and challenges in the light of new sea-level rise projections. The 23-member committee is expected to release a report later in 2009.

It makes sense to prepare now for rising seas, says Jessica Whitehead, regional climate extension specialist for the S.C. and N.C. Sea Grant Extension programs. "It's a lot cheaper to adapt today than to wait and try to adapt in 20 years."



VULNERABLE. *A high tide threatens to flood this marsh-front property on the back side of the Isle of Palms.*
PHOTO/WADE SPEES

"The public seems most concerned about beachfront erosion," says McCoy. "But there also will be early and dramatic changes in low-elevation places behind barrier islands and along tidal creeks, where you'll see salt marshes and high water moving into people's backyards and businesses."

Hundreds of South Carolina landowners have armored non-beachfront properties in an effort to protect them from shifting tides and currents. Under certain conditions, state regulators allow construction of new bulkheads and riprap, which are intended to prevent erosion of high ground from tidal creeks. Property owners have also built bulkheads and riprap along bay frontage and in areas behind barrier islands where high tides and waves threaten to take previously dry land.

But installing a hard structure along an estuarine shoreline cuts off a salt marsh's life support and can increase erosion nearby.

"If you build a bulkhead along a salt marsh and prevent it from migrating inland, then the marsh will eventually drown," says S.C. Sea Grant Consortium researcher James T. Morris, a marine scientist and director of the University of South Carolina (USC) Belle W. Baruch Institute.

As sea level inches upward, salt marshes migrate, colonizing dry land. Higher tides deposit sediments on lawns and forestlands, smothering grass and other terrestrial vegetation. Then salt-marsh plants, particularly *Spartina alterniflora*, take over and build coastal wetlands there. Salt marshes provide habitat for birds, nurseries and habitat for fisheries, pollution filters, and (perhaps in some locations) storm buffers for coastal communities.

"Salt-marsh migration is a process that's occurring every day," says Morris, "but it's usually so slow that people don't notice it. If we want to keep our marshes healthy, we need to allow them room to migrate." Otherwise, the marshes will get thinner and thinner geographically, and in some places they will no longer exist.

Some coastal marshes will disappear this century even in places that don't have bulkheads and other hard barriers to migration. Morris' studies at the North Inlet-Winyah Bay National Estuarine Research Reserve in Georgetown County show that half of the salt marshes there are on a trajectory to drown by the 2050s or 2060s if global sea-level rise continues to accelerate at its current pace.

"The North Inlet marshes could deal with 30 centimeters (one foot) of global sea-level rise over a century," says Morris. "But they probably can't deal with 30 centimeters over 40 years."

"Coastal society developed in a period of stable sea-level rise," says John Church, a research scientist with the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Hobart, Australia. But that time is over. "Today's sea-level rise is unprecedented during modern civilization. Now we need to rethink how extreme events [such as hurricanes] and sea-level rise are going to affect infrastructure and society. Many of the impacts are going to come through extreme events, and ice sheets are going to be a wild card. Observing, understanding, and modeling the oceans and the ice sheets are going to be key."

HISTORY OF SEA-LEVEL CHANGES

Shorelines have migrated back and forth many times throughout geological history. When the planet cools, coastlines generally move seaward because more water is locked up in ice. When the planet warms, coastlines move landward because ice is melting into the ocean, driving up global sea level; and that's what is occurring now.

Over the past million years, the Earth's climate has oscillated between cold times—popularly known as ice ages—and warmer times called interglacials. The ice ages have usually lasted for about 100,000 years, and the warmer periods tens of thousands of years. The last ice age ended about 12,000 years ago. Today, we are living in an interglacial called the Holocene.

Natural wobbles in the Earth's orbit have a strong role in initiating major climate cycles. Orbital wobbles cause subtle changes in the amount of sunlight that reaches the Earth at different latitudes. In other words, particularly sensitive places on the planet get warmer or cooler because of small changes in the Earth's path around the Sun. Then powerful "feedbacks" in the climate system kick in, accelerating the trend toward more warming or cooling.

For instance, consider an ice age transitioning to a warm interglacial. The Earth's orbital wobble slightly increases the amount of sunlight—and warmth—in an icy place like northern Canada. Ice and snow are excellent reflectors of solar radiation; they help keep the planet relatively cool by bouncing the Sun's rays back into space.

But when an ice sheet melts, the darker ground of mud and vegetation soaks in more solar radiation than before. This process increases global warming and also releases carbon that had been buried in permafrost.

The carbon rises into the atmosphere, where it captures solar radiation and causes further warming. Higher temperatures melt more ice, releasing even more CO_2. The increasing greenhouse effect, in turn, alters atmospheric and ocean currents that move heat to different places around the world, accelerating further ice melt at high latitudes and the poles and helping to turn the planetary "switch" in the direction of global warming.

Scientists have documented global feedback processes that are accelerating climate change today. Instead of an orbital wobble that sets in motion dramatic warming over thousands of years, industrial pollution and other human impacts are driving potentially profound climate change over decades or centuries.

Can we adapt again as the Earth warms? We have adapted numerous times before.

It was during an ice age that *Homo sapiens* emerged in Africa about 180,000 years ago. Our ancestors at that time were adapted to a cold, dry climate. Even so, they managed to survive a transition from an ice age to a warmer interglacial period that began

MATTER OF TIME. *An iceberg floats near Oates Coast, Antarctica.*
PHOTO/MIKE USHER, NATIONAL SCIENCE FOUNDATION

about 128,000 years ago.

Then, as if on schedule, the planet turned cold again 115,000 years ago, entering the most recent ice age, and *Homo sapiens* adapted again. It was during the last ice age, about 80,000 years ago, when our ancestors made a cognitive leap forward, fashioning more sophisticated tools such as harpoons, needles, and buttons. Eventually they began making musical instruments, organizing increasingly complex hunting and fishing expeditions, and using language to communicate.

And it was during the last ice age when some *Homo sapiens* left Africa about 50,000 years ago, exploring and settling in Asia, Europe, and Australia.

About 21,000 years ago, the Earth's temperature began an overall warming ascent toward the current interglacial, the Holocene, and many of the world's glaciers and ice sheets eventually lost water to the sea. It was a long, violent transition lasting thousands of years, with abrupt changes in temperature, especially at high latitudes. Global sea level rose as much as four meters per century. Many species tried to adapt as their habitats changed, but some failed and became extinct.

Our ancestors, however, adjusted to a warmer global climate. People settled in previously frozen regions that had been uninhabited for tens of thousands of years. As the giant continental ice sheets shrank and migration routes opened up from Asia to North America about 15,000 years ago, people began to explore and settle the Americas.

A little more than 8,000 years ago, Earth's climate settled down, and ever since it has been relatively temperate overall. Hunter-gatherers increasingly settled in permanent villages, cultivating wild grasses to plant crops and domesticating animals. The climate of the Holocene, archaeologists say, allowed communities to create food surpluses and increase trade, which led to increasingly complex agricultural societies and innovative cultures.

Modern human society, then, was nurtured by certain climate conditions out of which emerged heightened commerce and art, literature, science, and technology.

Throughout the years of the ancient Roman Empire, the Middle Ages, and the Renaissance, global climate remained relatively stable and global sea level changed little.

But in the 1750s, industrializing societies in Western Europe started burning fossil fuels (coal, oil, natural gas) for energy. Industrialization driven by fossil-fuel burning, of course, has since dramatically accelerated. The atmospheric concentration of carbon dioxide has risen from 280 parts per million (ppm) at the onset of the Industrial Revolution to 385 ppm today. The 2007 IPCC report says that the increase in CO_2 concentration since 1750 is accelerating at "an exceptionally fast rate," resulting in the Earth's warming.

Keep in mind that our species has never encountered a global climate influenced by an atmospheric concentration of CO_2 above 300 ppm. All through the history of *Homo sapiens*, even during various rapid climate changes of the past 180,000 years, CO_2 never rose above 300 ppm.

Today's rapid increase in atmospheric CO_2, of course, is the most pervasive driving force behind climate

Volunteers plant beach grass and build fencing to establish dunes, which can reduce erosion, at the Isle of Palms as part of "Doin' the Dunes," a public-service program.

PHOTO/APRIL TURNER, S.C. SEA GRANT EXTENSION PROGRAM

NATURAL DISASTERS AND SEA-LEVEL RISE

U.S. Atlantic and Gulf coasts are particularly vulnerable to rising sea level over the next century because human-induced global warming will likely strengthen tropical cyclones in the Atlantic basin.

Most—but not all—computer simulations show that the numbers of very intense Atlantic hurricanes are likely to rise over the next century because of climate change, according to Thomas Knutson, a senior scientist at the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey.

"The rarest, most intense simulated hurricanes (Category 4 and 5) occur up to three times as often in the late twenty-first century," says Knutson.

The most recent studies point to less frequent hurricanes in the future but those that do form are likelier to become more intense. Stronger wind shear in the future will probably tear many storms apart as they try to form. But storms that do manage to form and overcome wind shear will probably become very powerful hurricanes.

Property insurers, though, aren't waiting for computer models and scientists to reach a consensus. California-based Risk Management Solutions (RMS), the world's largest catastrophe modeler, is advising insurers to prepare for significantly costlier damage claims in coastal areas from stronger storms spawned by global warming.

"We can expect more intense hurricanes going forward," says Robert Muir-Wood, the RMS chief research officer. As a result, hazard insurance premiums can be expected to rise in many U.S. coastal areas.

warming. The present CO_2 concentration—385 ppm—is about 30 percent above its highest level over the past 800,000 years. What's even more troubling is that now atmospheric CO_2 concentration is increasing at a dramatically faster rate than during any time since our species emerged in Africa, and it will further accelerate in the future—unless greenhouse emissions are drastically reduced.

During past transitions from ice ages to interglacials and back again, the world's *Homo sapiens* population was very small. People lived in family-based groups as hunter-gatherers.

Now, the planet's human population is roughly 6.7 billion, and it's expected to reach 9 billion by 2050. Much of this population growth is occurring along some of the most disaster-prone regions.

In 1950, New York City was the world's only "megacity," defined as a city with more than 10 million people. Now there are 17 megacities around the globe, and 14 are located in coastal areas. The United Nations (UN) Population Division anticipates four new megacities by 2015, including Tianjin, China; Istanbul, Turkey; Cairo, Egypt; and Lagos, Nigeria. Each but Cairo is located on a coastline.

RETREAT OR ENGINEER?

There's no question that communities around the world—especially those in coastal areas—will have to adapt to a changing climate.

"Adaptation is inevitable," says R. K. Pachauri, chair of the IPCC. But "very soon we will exceed the capacities of societies to adapt."

Megacities constructed on major river deltas—Mumbai, India, and Dhaka, Bangladesh, for instance—will face serious adaptation challenges. River deltas are already sinking as loose sediments compress together. Moreover, much of the housing in megacities is built outside of any official plan or constructed as illegal settlements, according to a 2007 study by Columbia University's Center for Sustainable Urban Development.

Hundreds of millions of people in these sprawling communities lack adequate drinking water and sanitation, and they would likely face public-health catastrophes in an era of increased natural disasters.

Wealthy nations such as the United States have technical and scientific capacities to retreat inland in an orderly fashion from the ocean edge in less populated areas, elevate buildings and infrastructure, and build barriers and buffers around densely populated urban centers. But do they have the political will to abandon flood-prone coastal areas?

Two decades ago, South Carolina became one of the first states to establish a policy of retreat from rising seas, though this effort has been only modestly successful.

In the 1980s, powerful storms and large waves were knocking down oceanfront houses along some eroding shorelines. To protect their properties, some landowners built seawalls and other hard erosion-control structures to hold back the ocean.

But seawalls allow waves to scour away sand and prevent beaches from naturally migrating inland. As a result, the beachfront disappears under water, and the public loses access to the shoreline, a public trust land. South Carolina leaders became worried about impacts from seawalls on the valuable beach-tourism industry.

In 1988, South Carolina's legislature enacted the Beachfront

BARRIER. ***A city worker repairs a seawall in downtown Beaufort. Many coastal communities will eventually have to decide where to armor shorelines and where to retreat from the ocean as sea level rises.***

PHOTO/WADE SPEES

HOLDING ON. *"Our beach is doing well," says Mayor Burley Lyons of Edisto Beach, in front of the state's only rebuilt beachfront seawall since the Beachfront Management Act was passed in 1988. In 2006, a project to nourish Edisto Beach temporarily raised the shoreline here and extended it seaward. "We hope it will last 10 years," says Lyons, "unless along comes another Mr. Hugo or one of those bad boys, and then we're in trouble."*

PHOTO/WADE SPEES

Management Act to guide the state through a retreat from the sea. New homes had to be set back from the ocean, and construction of new seawalls was prohibited. Today, a seawall built before 1988 cannot be rebuilt if 50 percent of it has been destroyed by a storm.

The Beachfront Management Act, however, doesn't apply to the state's marshfronts and bayfronts—only to ocean beaches. When the law was passed in 1988, state lawmakers and resource managers weren't thinking about potential future losses of marshes to sea-level rise. But marshes are also migrating inland and will continue to do so.

A crucial underpinning of the 1988 state law is that when coastal storms would destroy the state's older beachfront seawalls, shorelines would be allowed to naturally migrate inland over time. This beach migration would eventually undermine oceanfront property and homes. Homes would collapse or they would have to be abandoned or relocated farther inland.

The seawall provision, then, is an important regulatory mechanism intended to drive society's retreat from the ocean, particularly after storms. But enforcing the seawall provision would eventually mean that some coastal property owners would lose homes and land without compensation from the state.

Only one private-property owner—Helen James of Edisto Beach—on the South Carolina coast has lost an entire seawall to the ocean since 1988, but she was able to rebuild it because of unique circumstances. Edisto Beach's erosion rate was so extreme during the late 1990s and early 2000s that the state's beachfront-setback rules didn't keep pace with changing conditions there. The setback rules are updated every 10 years.

After her seawall and home were destroyed in a storm, James still had enough high land to construct a seawall landward beyond the state's jurisdiction. The dry section of her beachfront property fell within the jurisdiction of the town of Edisto Beach, which allowed her to rebuild the seawall. She has not rebuilt her home.

The reality is that the state's seawall provision in regard to reconstruction—a linchpin of the S.C. Beachfront Management Act—has never been challenged in court. No one has lost a seawall and been prohibited from rebuilding.

FORCED RETREAT. *Jeff Atkins, manager of Hunting Island State Park, has seen beach cabins and a coastal road lost to the sea over the past two years. Valuable infrastructure will continue to be damaged by shoreline change in coming decades.*
PHOTO/WADE SPEES

More than 20 years after its passage, "the crux of the Beachfront Management Act—of retreat—has not been tested," says Braxton Davis, director of the policy and planning division of the S.C. Department of Health and Environmental Control-Office of Ocean and Coastal Resource Management (SCDHEC-OCRM).

Why has only one seawall been destroyed in more than two decades along the South Carolina coast? The state hasn't been hit by a major hurricane since Hugo in 1989. When another catastrophic storm hits the coast, there could be many more seawalls destroyed. Another reason is that so many beachfront communities in South Carolina have as an alternative artificially nourished their shorelines with extra sand.

In decades past, communities have relied on sand mined from pits on land and trucked it to the eroded beach. Now they dredge sand from offshore or from nearby tidal inlets and shoals and pump it onto beaches. There are very large volumes of sand trapped in tidal inlets and shoals that could be used for continuing nourishment of island beaches, though this is controversial for navigational and environmental reasons.

Nourishment projects, which are expensive, temporarily raise shorelines and extend beaches seaward. Nourishment has often provided a buffer against erosion and storm damage to seawalls and homes. Some beaches have been repeatedly engineered in this way; the overall net effect has been to continuously build and rebuild beaches higher and farther into the ocean. These engineering feats occur so frequently that many South Carolinians haven't really understood their scale.

"We have built the South Carolina shoreline upward and seaward because of nourishment," says Gayes of Coastal Carolina University. "It's a big signal" when studying the impact of sea-level rise on the state's shorelines.

DEFENDING TO THE DEATH

Many U.S. beaches probably could be continuously nourished and otherwise stabilized to withstand an additional one-and-a-half to three feet of relative sea-level rise, according to a January 2009 report by the U.S. Climate Change Science Program. There are limits, however, to what nourishment can achieve. Over time, nourished barrier islands would become shorter and skinnier—spits of oceanfront in a deepening sea—and the back side of the islands would disappear under water.

Some coastal communities could also build levees, dikes, and other hard structures to protect estuarine shorelines, the report points out.

But coastal cities would lose their waterfront views to levees, dikes, and other flood-protection structures. Land behind such structures would have to be continually pumped out whenever it rains, and people would be exposed to dangerous flooding during hurricanes.

Flooding would also increase in places that aren't armored against the ocean—unless long stretches of coastline were protected with hard structures, and that would be prohibitively expensive.

Armoring the coast, moreover, would destroy coastal wetlands, which would be squeezed between flood-protection structures and a rising sea. By century's end, many shorelines along the Atlantic seaboard will almost certainly experience wetland losses and storm flooding similar to those experienced now in South Louisiana and New Orleans, says Abby Sallenger, an oceanographer with the U.S. Geological Survey.

Since the 1930s, Louisiana has engineered its entire coast with flood-protection and navigation projects, which are primarily responsible for the state losing 34 square miles of wetlands every year. As coastal wetlands have disappeared, the ocean has crept closer and closer to New Orleans, which has been protected behind levees and floodwalls, some of which failed during Hurricane Katrina.

Over the past two decades, development along the South Carolina coast hasn't retreated from the ocean, despite a declared policy to do so. Since 2001, state regulators have permitted hundreds of erosion-control devices—bulkheads, riprap, and revetments—along tidal creeks, bay frontage, and in areas behind barrier islands. Again, the S.C. Beachfront Management Act's prohibition on new seawalls and other hard structures does not apply to estuarine areas.

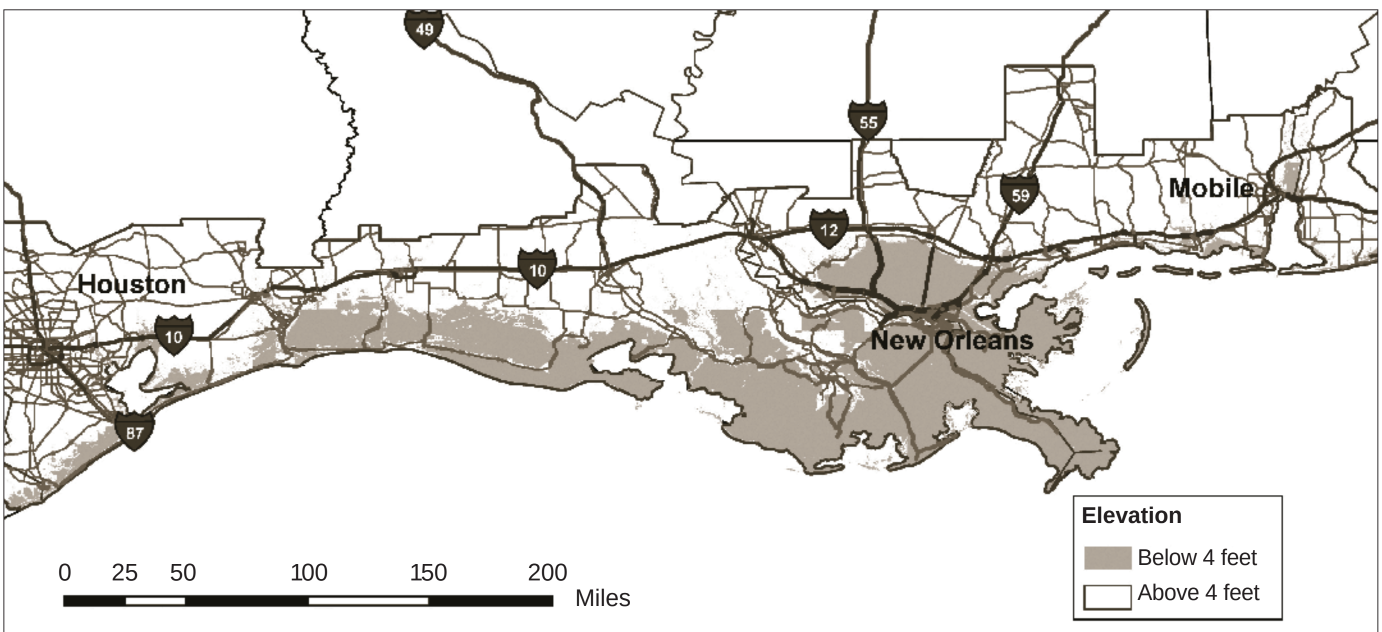
State officials say they consider issuing a permit for a bulkhead or other erosion-control device along a tidal creek or bayfront only when the waterway is taking away high ground. A landowner would not receive a permit if salt-marsh vegetation has migrated into an upland area and there is no evidence of erosion from rising water.

Eventually, however, much of the state's estuarine shoreline could be hardened if today's policies remain in force. As sea level rises, wetlands will migrate upland, tidal and ocean currents will threaten high ground, and many landowners would seek to protect their properties with hard structures.

Over time, many more lowcountry waterways could look like armored Shem Creek in front of Red's Ice House. "If you build a bulkhead around a marsh and trap it from migrating, you'll eventually have a seawall facing the open ocean," says James T. Morris of the University of South Carolina.

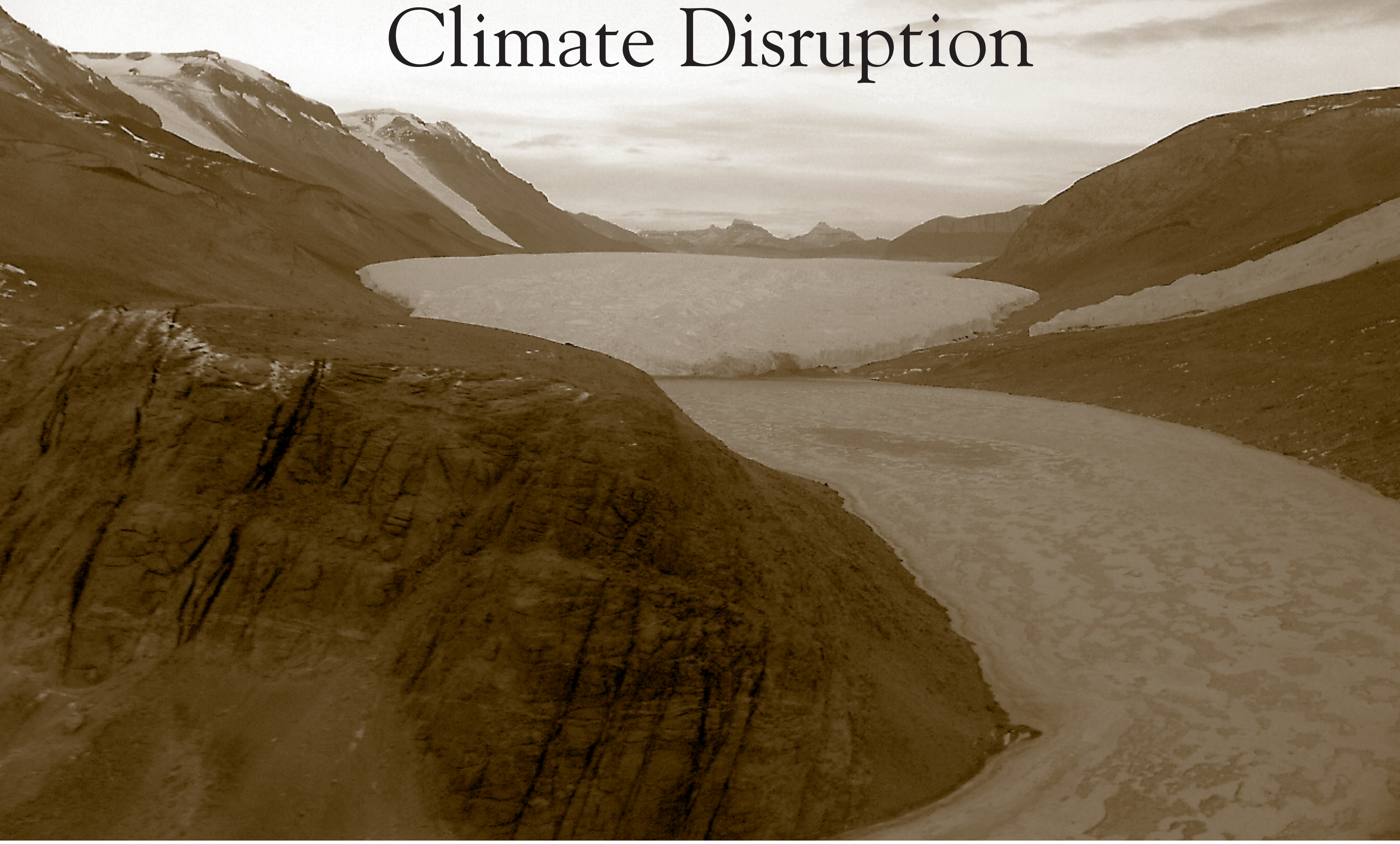
Meanwhile, nourishment projects in South Carolina continue to extend many beachfronts temporarily seaward, says Paul Gayes. That is, instead of retreating from the sea, communities are creating new beachfront farther into the ocean. In a few communities, property owners are allowed to construct new homes and condominiums on these engineered landscapes as if they were permanent.

Says Gayes, "You can creep along year after year, making a series of what seem to be small decisions to engineer the coastline. But someday you will reach a point of no return, and you will find yourselves defending these places to the death. New Orleans didn't set out a century ago to become a city six feet under sea level behind seawalls. There were many decisions over decades that led South Louisiana to harden parts of its shoreline and lose its coastal wetlands. We have to remember that what we do today will affect what the coast will be like in a century."



Some stretches of the Gulf Coast could experience six to nine feet of relative sea-level rise by 2100 because of a combination of regional and global influences, scientists say. Today, 24 percent of interstate highway miles in the Gulf Coast region are beneath four feet mean sea level. MAP GRAPHIC/U.S. CLIMATE CHANGE SCIENCE PROGRAM

Polar Ice Shows Climate Disruption



DYNAMIC FLOW. ***A view of the west lobe of Lake Bonney and the Taylor Glacier in Antarctica. Because of climate change, many ice-sheet glaciers are flowing faster into the ocean, where ice melts and raises global sea level.***
PHOTO/JOHN PRISCU/NATIONAL SCIENCE FOUNDATION

Global warming has already set in motion changes in polar ice sheets that will last centuries or longer, glaciologists say. Scientists are particularly worried about deteriorating conditions of the West Antarctic Ice Sheet, a gigantic landmass on the Pacific Ocean side of the continent.

If the entire West Antarctica Ice Sheet falls into the ocean, global sea level would rise by 11 feet, though it would probably take centuries for that to occur. Still, no one really knows how fast such a big melt could happen.

Until recently, scientists couldn't predict behavior of ice-sheet changes at the poles. In fact, the 2007 IPCC's Working Group I forecast a modest global sea-level rise of just six inches to two feet by the end of this century because the math of ice-sheet dynamics is so complicated that it was left out of the report.

But glaciologists have since collaborated on an international effort to learn more about the poles. From 2007 to 2009, thousands of scientists from 62 nations joined efforts to study the Arctic and Antarctic as part of the International Polar Year, a research and education project.

Now scientists say they have a better understanding of synergies among climate change, ocean processes, and ice sheets in West Antarctica.

The West Antarctic Ice Sheet has the most complicated geology of the world's three major ice sheets, including Greenland and East Antarctica. It is moored precariously on a series of islands, and most of it is below sea level. The ice sheet also extends beyond the continental edge into the surrounding Southern Ocean, where the giant extensions, called ice shelves, float on seawater.

Within the West Antarctic Ice Sheet is a network of icy freshwater flows called glaciers. To the naked eye, a glacier appears as a stable mass of ice, but actually it moves seaward very slowly, at a pace of a few miles per year. Downhill toward the coast, the glacier flows year after year until a floating ice shelf, hundreds of meters thick, contains the glacier's progress like a cork stopping fluid in a bottle.

Today, climate change is disintegrating the ice shelves but in an indirect way, scientists have learned. Climate change is speeding up winds above the Southern Ocean surrounding Antarctica. This process is altering ocean currents, drawing an upwelling of ocean heat from deeper water to the continental shelf and pushing this heat against the coastal shelves, eroding them from below.

"Winds are changing, and this is bringing warm water to the floating ice of West Antarctica," says Richard Alley, a climate scientist at Pennsylvania State University.

The Southern Ocean has a very cold top layer and a very cold bottom layer, but at intermediate depths in the ocean abyss—600 to 1,000 meters down—seawater is exceedingly warm.

"There's a huge amount of heat there," says Robert Bindschadler, a glaciologist and chief scientist at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center in Greenbelt, Maryland. "I'm worried about all that heat in the ocean. Only a tiny fraction of that heat is needed to melt the shelves. Far more heat can get to the ice shelves from the ocean than from the atmosphere."

The melting of West Antarctica's ice shelves alone doesn't directly affect sea level because they are already in the ocean. Still, the loss of the ice shelves is important because they help stabilize—or contain—restless parts of the vast ice sheet.

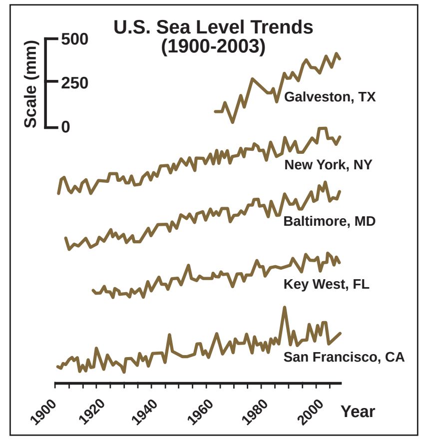
Remember, the thick shelves are like corks in the ice-sheet bottle. When they disintegrate, the glaciers flow faster into the ocean, where they melt and raise global sea level.

Recent observations show that two giant glaciers, Pine Island Glacier and Thwaites Glacier, on the coast of West Antarctica are disappearing at an accelerating pace. Pine Island Glacier alone is losing 46 billion tons of water each year.

In addition, observations from aircraft and satellites beginning in the 1990s have shown that the geographic area and intensity of summer melting of Greenland are progressively growing larger. Meanwhile, on Greenland, faster-moving glacial streams once corked by ancient moraines—pileups of ancient sediment and rocks—are bursting through these barriers and pouring rapidly into the coastal ocean.

This combination of polar melting and glacier changes on Antarctica and Greenland is adding 300 to 400 gigatons (a gigaton is 1 billion tons) of water to the global ocean per year. This process drives up global sea level 1 mm (slightly less than the width of one dime) annually. Changes in polar ice will inevitably accelerate in the future under pressure from climate change, scientists say.

"Sea level won't stop at 2100," says Stefan Rahmsdorf of the Potsdam Institute for Climate Impact Research in Germany. "We are looking at



Relative sea-level rise, a complicated combination of local and global influences, is different in different places. It will continue to increase faster along large stretches of the U.S. Gulf Coast, where the land is sinking rapidly, than along most of the U.S. East Coast.

GRAPHIC/ENVIRONMENTAL PROTECTION AGENCY AND PROUDMAN OCEANOGRAPHIC LABORATORY

several meters of sea-level rise over several centuries unless we slow greenhouse-gas emissions quickly."

But even if we suddenly stopped putting greenhouse gases into the atmosphere, industrial society's impacts on ice sheets and the entire climate today "will last longer than Stonehenge," writes David Archer, an oceanographer at the University of Chicago, in a 2009 book. "Longer than time capsules, longer than nuclear waste, far longer than human civilization so far."

Reading and Web sites

Archer, David. *The Long Thaw: How Humans are Changing the Next 100,000 Years of Earth's Climate.* Princeton, N.J.: Princeton University Press, 2009.

Satterthwaite, David and others. *Building Climate Change Resilience in Urban Areas and Among Urban Populations in Low- and Middle-Income Nations.* A report by Columbia University's Center for Sustainable Urban Development, 2007. **csud.ei.columbia.edu/?id=library_papers**

Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, January 2009. **www.climatescience.gov/Library/sap/default.htm**

Global Climate Change Impacts in the United States. A report by the U.S. Global Change Research Program, June 2009. **globalchange.gov/publications/reports/scientific-assessments/us-impacts**

Intergovernmental Panel on Climate Change. **www.ipcc.ch**

NASA and the International Polar Year **www.nasa.gov/mission_pages/IPY/main**

NASA Goddard Space Flight Center **www.nasa.gov/centers/goddard/home**

S.C. Department of Health and Environmental Control-Office of Ocean and Coastal Resource Management. **www.scdhec.gov/environment/ocrm**

NEWS & NOTES

Biological record reveals ancient shoreline change

How rapidly could South Carolina's shorelines erode as sea level continues to rise? Over the past 70 years, sea level measured in South Carolina has risen by nearly one foot. Over the next 70 years, the state could see similar or potentially much larger changes in sea level. South Carolina already spends significant sums to protect and maintain many stretches of its shoreline through beach nourishment projects.

Climate change has driven most long-term coastline migrations. When the planet's temperature turns colder, coastlines generally relocate seaward because more water is locked up in ice. When the planet becomes warmer, coastlines migrate landward because ice melts into the ocean, driving up global sea level. Since the peak of the last ice age 18,000 years ago, global sea level has risen about 360 feet, sometimes slowly and steadily, sometimes explosively.

Fifteen miles off Murrells Inlet, South Carolina, a large number of tree stumps and peat deposits can be observed on the sea floor 60 feet below the sea surface. These materials, radiocarbon-dated at about 12,500 years old, demonstrate that the sea has risen and the shoreline has migrated landward along the South Carolina coast.

On much shorter time periods, sea-level changes directly measured by tide gauges in Charleston and Myrtle Beach show that sea-level rise is not smooth but has annual and decadal variations related to local conditions and climate.

Understanding past behavior of the shoreline could provide important guidance about how sea level might have changed on relatively brief time scales and spatial scales.

Amy Tyillian, a Coastal Carolina University student, takes a core sample to search for deposits of an ancient forest floor inundated by a rising sea thousands of years ago.
PHOTO/COASTAL CAROLINA UNIVERSITY

"We need more details of how sea level changed and how the coast responded in the past—details that will be extremely helpful in attempting to manage our coastal zone in the future," says S.C. Sea Grant Consortium researcher Paul Gayes, director of the Center for Marine and Wetland Studies at Coastal Carolina University.

Now, Gayes and his colleagues are searching for evidence of a more precise record of the submergence of the South Carolina coast over the past 4,000 to 5,000 years. Some clues could be found in biological remnants of ancient shorelines buried beneath coastal waterways.

As sea level rises, salt marshes migrate inland and take over uplands. Higher tides deposit sediments on lawns and forestlands, a process that kills grass and other terrestrial vegetation. Then salt-marsh plants, particularly *Spartina alterniflora,* build coastal wetlands there.

Eventually, rising sea level and further sediment depositions bury evidence of this marshfront vegetation beneath the estuary bottom. Tidal creeks meander through the lowcountry, in most cases disrupting and erasing the biological record. Moreover, biological activity—biogenesis—usually decays and breaks down these remnants of ancient shorelines, and they disappear.

In the early 1990s, however, scientists located an apparently intact biological record of an ancient shoreline in Murrells Inlet. Now, S.C. Sea Grant Consortium researchers are taking additional core samples along the Murrells Inlet bottom and analyzing them. The scientists are also studying other potential sites along the South Carolina coast, including the Hilton Head Island area, for additional evidence of ancient shorelines.

"We are looking for the leading edge of the shoreline, for that first element of marsh grass that creeps over the upland floor and to track its progress over time," says Gayes.

This project could help provide information that South Carolina lacks: a coast-wide set of three to four accurate records of sea-level change over thousands of years.

"You might expect different rates of sea-level rise in different locations along the South Carolina coast," says Gayes.

That's because sea level is relative. The land adjusts over time because of geological warping or locally intensive pumping of groundwater. Shifts in

NEWS&NOTES

coastal winds and currents also adjust water level. Some oceanfront areas are far more dynamic than others. Sections of Hunting Island's shoreline, for instance, are eroding rapidly, while other beaches in the state are accreting. South Carolina's shoreline can be expected to respond differently from place to place under future changes in sea level.

The Consortium research could provide a systematic study of causes and consequences of differences of past sea-level change in various locations along the state's shoreline. It also could provide data for a model-predicted acceleration in regional sea-level rise related to global warming.

Coastal Heritage wins five awards

Coastal Heritage, a quarterly publication of the S.C. Sea Grant Consortium, received five awards in competitions during 2008-2009. The periodical won a Distinguished Award from the Society of Technical Communications (STC) Carolina chapter competition and an Award of Excellence from the STC international competition. The rigorous judging process was based on content and organization, copy-editing, visual design, and creativity. *Coastal Heritage* was on display at the 2009 Technical Communications Summit in May in Atlanta, Georgia.

In addition, *Coastal Heritage* received an Award of Excellence in the Low-Budget Publications category in the Council for Advancement and Support of Education (CASE) Region IV competition. The magazine also received an Award of Merit in the Other Magazines category.

Finally, *Coastal Heritage* won a 2009 APEX Award of Excellence in the Magazines and Journals category.

Subscriptions are available upon request by contacting Annette Dunmeyer at (843) 953-2078 or via e-mail at Annette.Dunmeyer@scseagrant.org.

Current and past issues are available on-line at www.scseagrant.org/Products.

Beach Sweep/River Sweep call for volunteers

Join S.C. Sea Grant Consortium and S.C. Department of Natural Resources for the 21st annual Beach Sweep/River Sweep on Saturday, September 19, 2009. Last year, over 6,500 dedicated volunteers removed 67.5 tons of debris from our beaches, marshes, and waterways.

Beach Sweep/River Sweep—South Carolina's largest one-day cleanup—is held each year in conjunction with the Ocean Conservancy's International Coastal Cleanup. There are many existing cleanup sites across the state from which to choose, and the coordinators are compiling a list of needy areas that require attention.

To volunteer on the coast, contact Susan Ferris Hill at (843) 953-2092 or susan.ferris.hill@scseagrant.org. Volunteers who want to help inland may contact Tanji Paulin at (803) 734-9100 or paulint@dnr.sc.gov. For more information, visit www.scseagrant.org/Education and www.dnr.sc.gov/water/envaff/river.

Volunteers with the U.S. Navy collected over 2,000 pounds of debris from creeks around the Naval Weapons Station in Goose Creek, S.C., during the 2008 Beach Sweep/River Sweep.
PHOTO/TERRENCE LARIMER, U.S. NAVY

S.C. Sea Grant Consortium
287 Meeting Street
Charleston, S.C. 29401

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EBBS & FLOWS

Hurricane Hugo 20th Anniversary Symposium on Building Safer Communities

Charleston, South Carolina
October 22-23, 2009

This symposium will solicit and present new information on significant changes in coastal-construction practices since Hugo. State-of-the-practice ideas, research results, and issues affecting building safety and damage reduction will also be discussed, benefitting design professionals and builders/developers.

For more information, visit www.atcouncil.org.

Oceans '09

Biloxi, Mississippi
October 26-29, 2009

The conference theme, "Marine Technology for Our Future: Global and Local Challenges," reflects the effort of the ocean's community acting locally to address global issues. This year's conference will cover four topics: Operational Oceanography, Coastal Restoration, Ocean Observing Systems, and Lessons Learned from Recent Hurricanes.

For more information, visit www.oceans09mtsieeebiloxi.org or e-mail info@oceans09mtsieeebiloxi.org.

Estuaries and Coasts in a Changing World

Portland, Oregon
November 1-5, 2009

The 20th biennial conference will be held in the Pacific Northwest, where climate and oceanographic changes are affecting entire watersheds. These changes are also observed and studied in a variety of coastal and estuarine habitats, and conference participants will discuss the important relationships between coastal regions over time and spatial scales. For more information, visit www.sgmeet.com/cerf2009 or e-mail cerf2009@sgmeet.com.

Subscriptions are free upon request by contacting: Annette.Dunmeyer@scseagrant.org

ATTENTION SCHOOL TEACHERS! The S.C. Sea Grant Consortium has designed supplemental classroom resources for this and past issues of *Coastal Heritage* magazine. *Coastal Heritage Curriculum Connection*, written for both middle- and high-school students, is aligned with the South Carolina state standards for the appropriate grade levels. Includes standards-based inquiry questions to lead students through explorations of the topic discussed. *Curriculum Connection* is available on-line at www.scseagrant.org/education.